Design Process for the Advanced Photon Source Fast Orbit Feedback System Upgrade

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Workshop on Next-Generation Fast Orbit Feedback Systems for Storage Rings

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Design Philosophy

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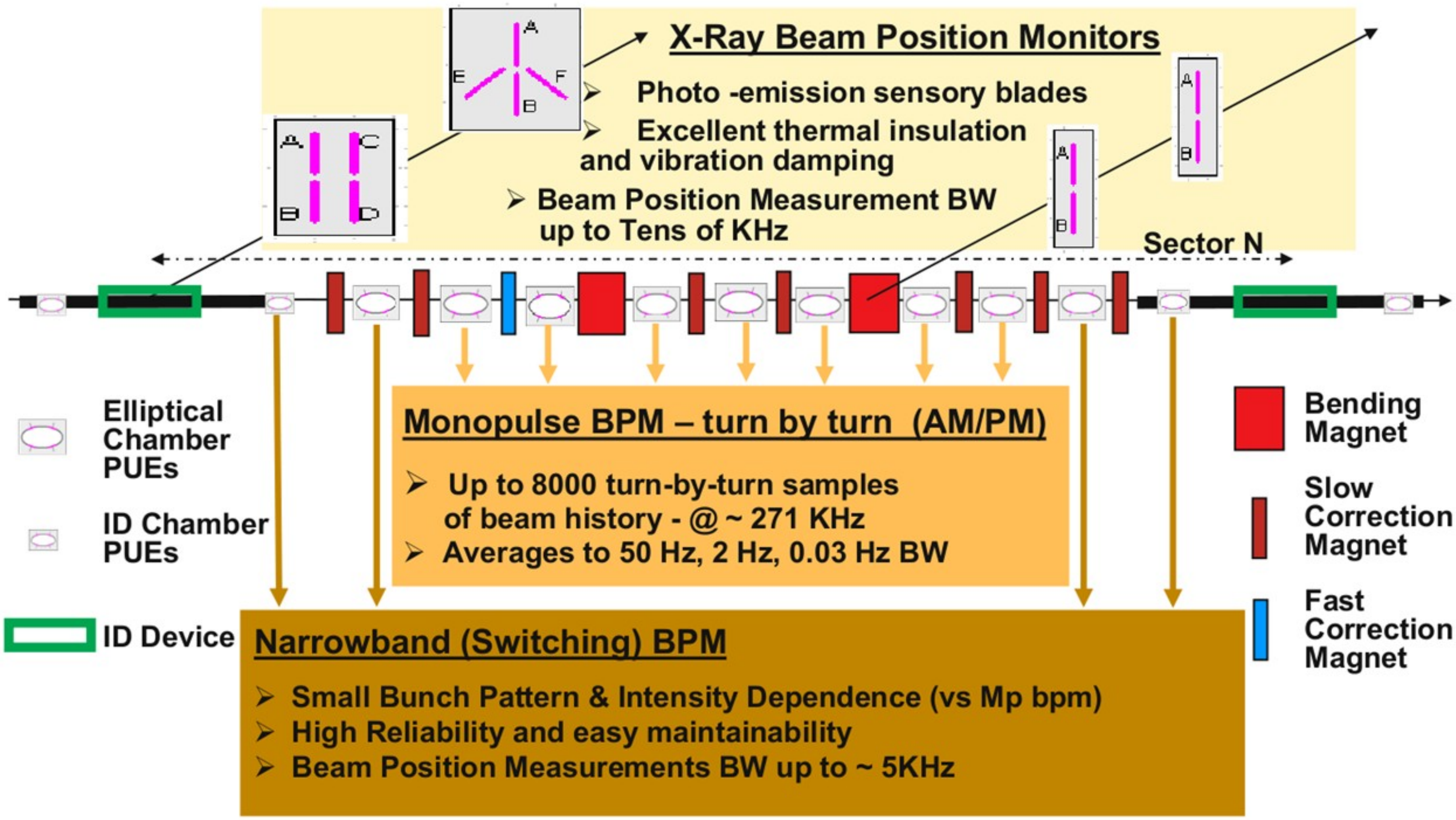
- What shall be supersedes what can possibly be.
- What can possibly be should be within grasp of what shall in fact be.
- What now is provides enormous leverage towards what shall, or can possibly be.
  - If only we have the conviction to learn from our mistakes past, present, and future.

Design Process

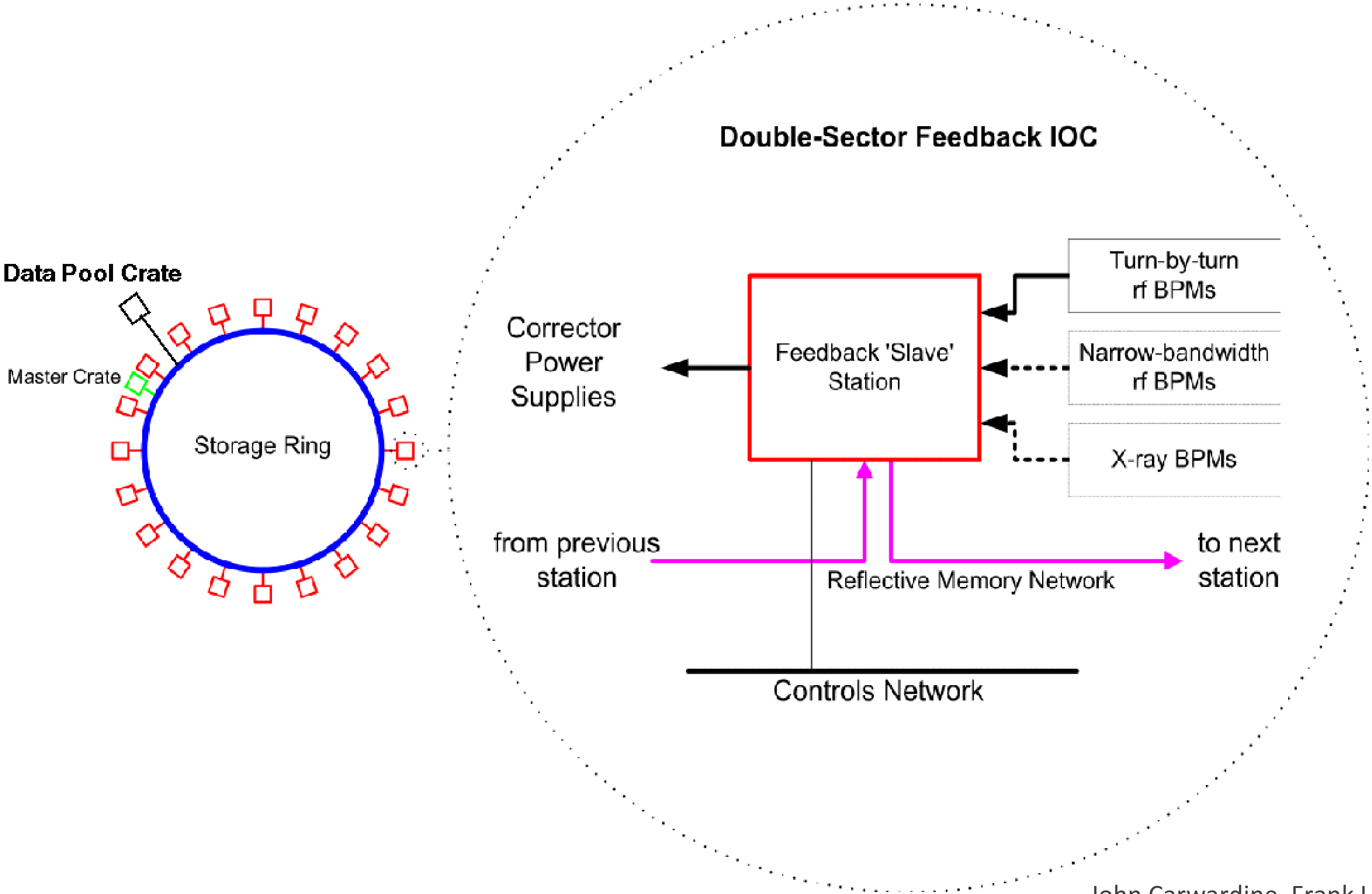
- The hardware and interfaces, while challenging, will be straightforward.
- The algorithms to be run on the hardware is perhaps more challenging.
- We have a machine, soon to have a full complement of turn-by-turn bpms.
- We will use the machine we have to simulate the machine we want.
  - Based on measured beam temporal and spatial structure
  - Based on measured steering corrector response
  - Using already-familiar operational orbit correction configuration tools
- An extensive code validation phase will compare simulation with experiment.
- Only then will we start extrapolating.

What is and was – APS Beam Position Monitoring



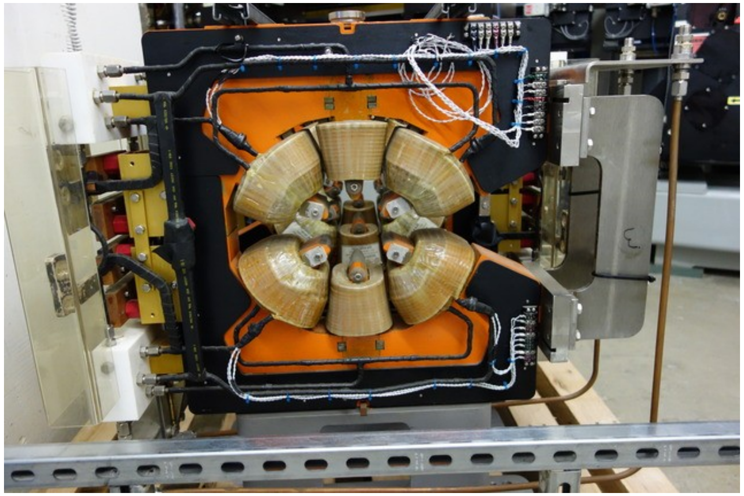
Om Singh c. 2004

Existing APS Fast Orbit Feedback Architecture

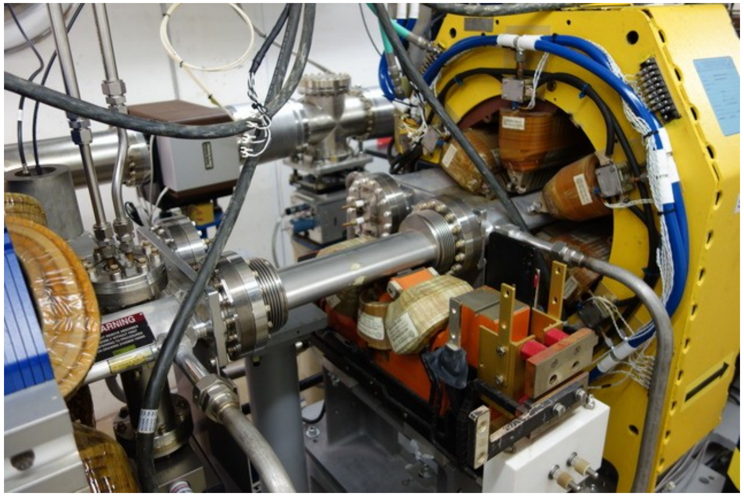


John Carwardine, Frank Lenkszus

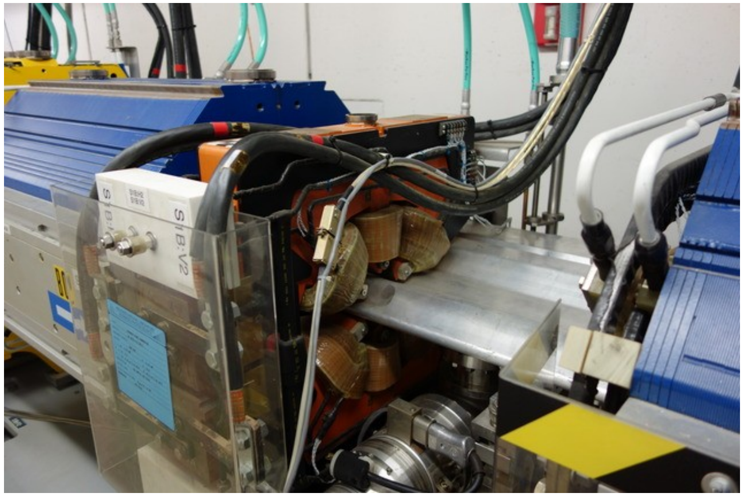
The Hardware



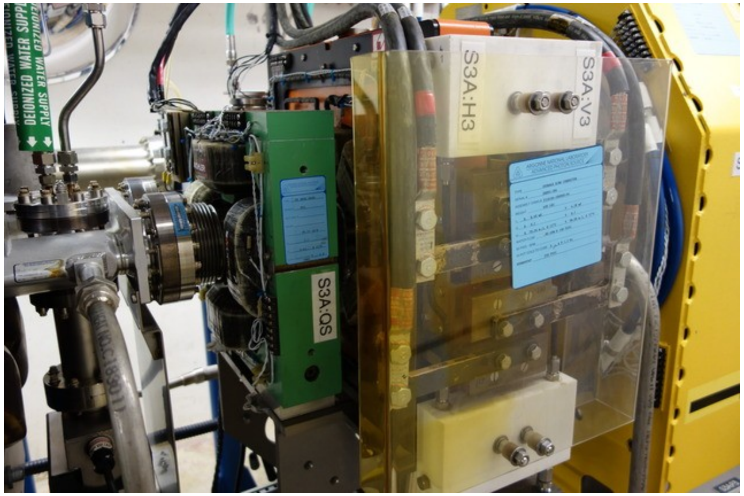
Six-pole combined H/V correctors



Split fast corrector with spool piece
(Note xbpm in background)



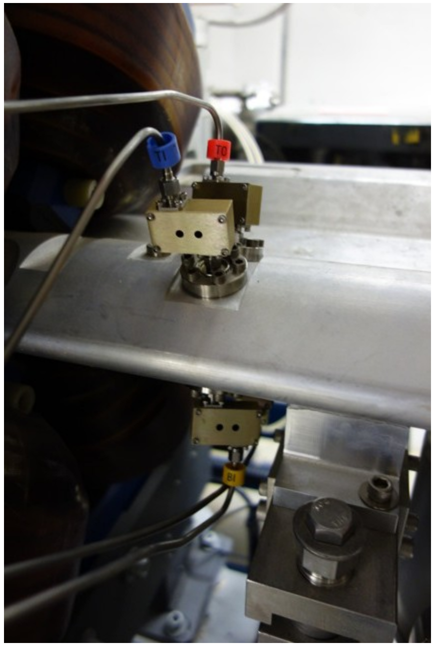
Slow corrector with aluminum chamber



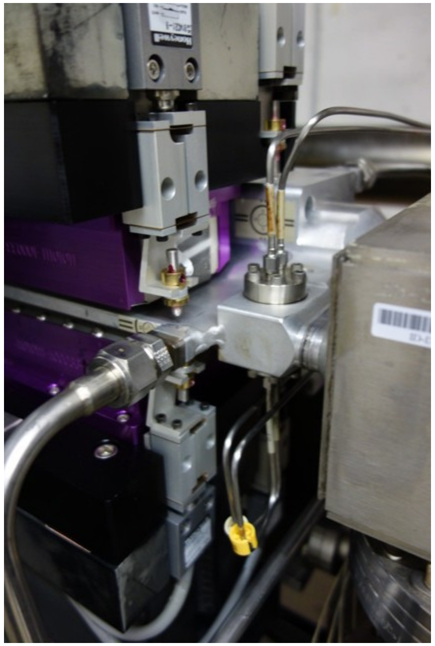
Fast corrector with solid-core skew quad

Pickup Electrodes

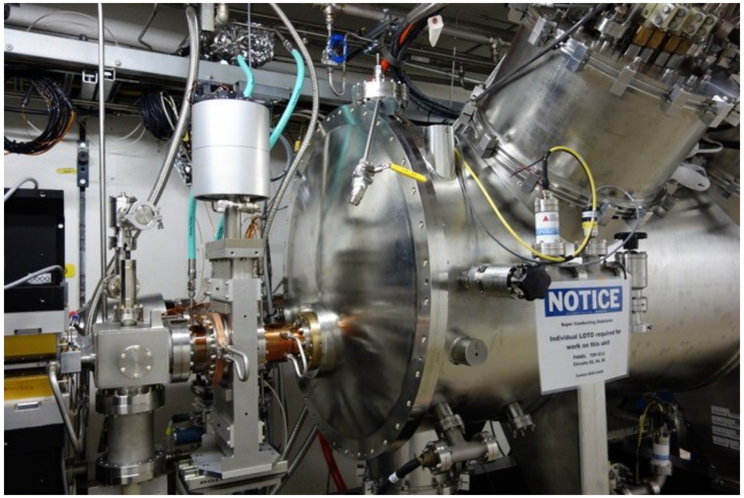
1-cm dia. buttons



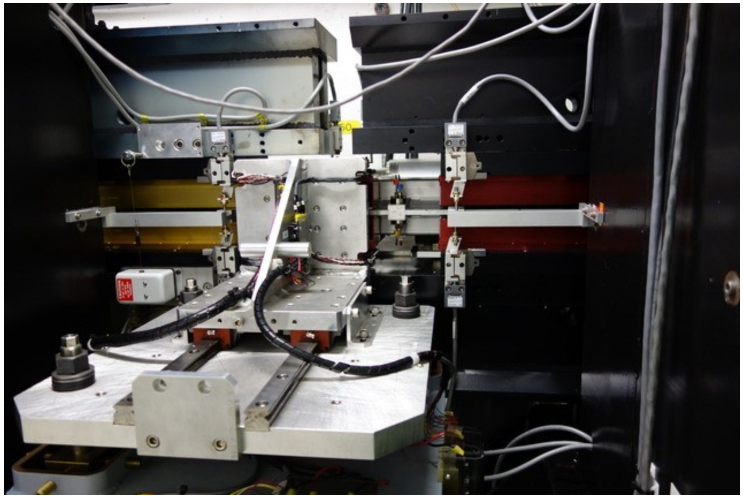
With 352 MHz matching networks



4-mm dia. Buttons @ IDs



Between hybrid undulator and SCU



Between two hybrid undulators

Electronics

Bergoz

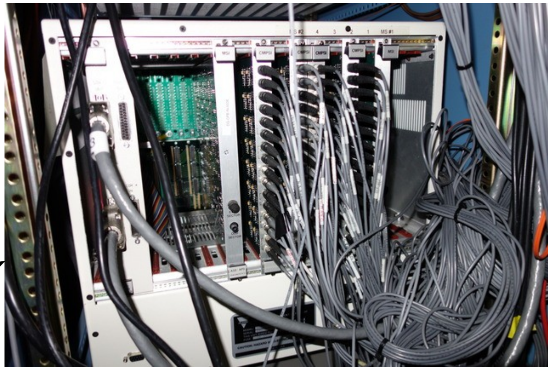
Feedback Crate

Front

Rear

BSP-100s

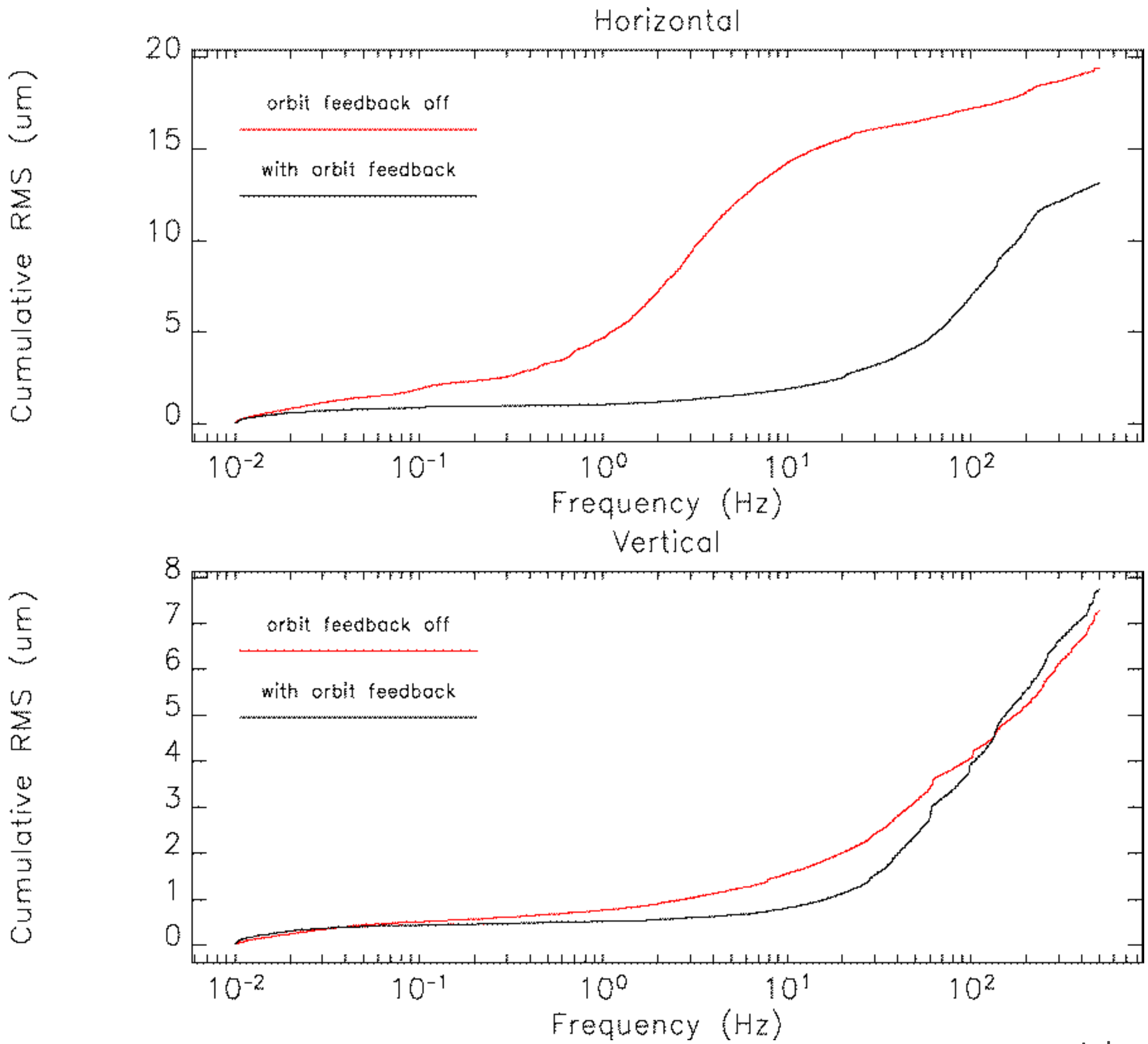
Monopulse Receivers



Every corrector gets two fibers

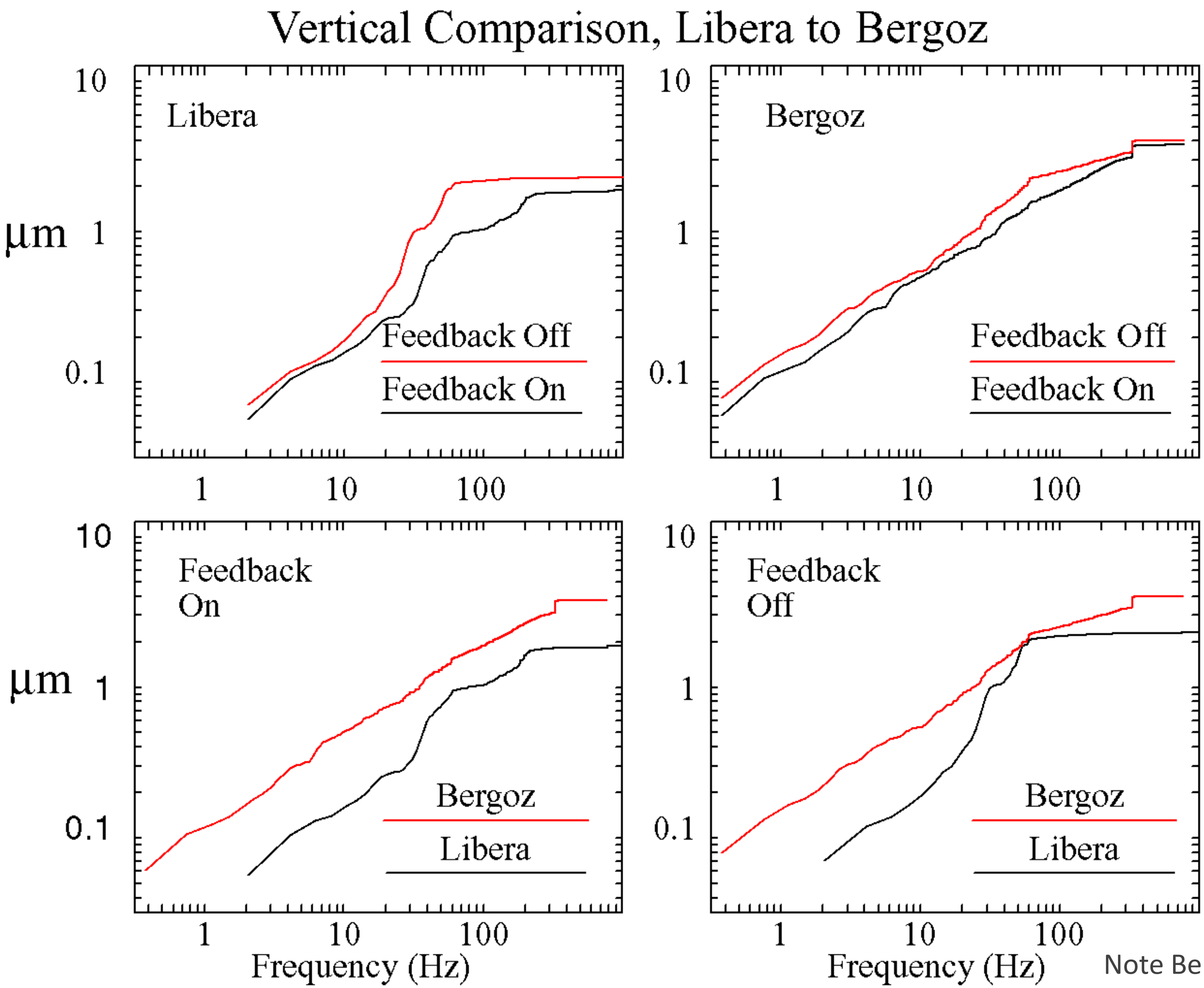
X-ray BPM Preamps

Existing Feedback Performance



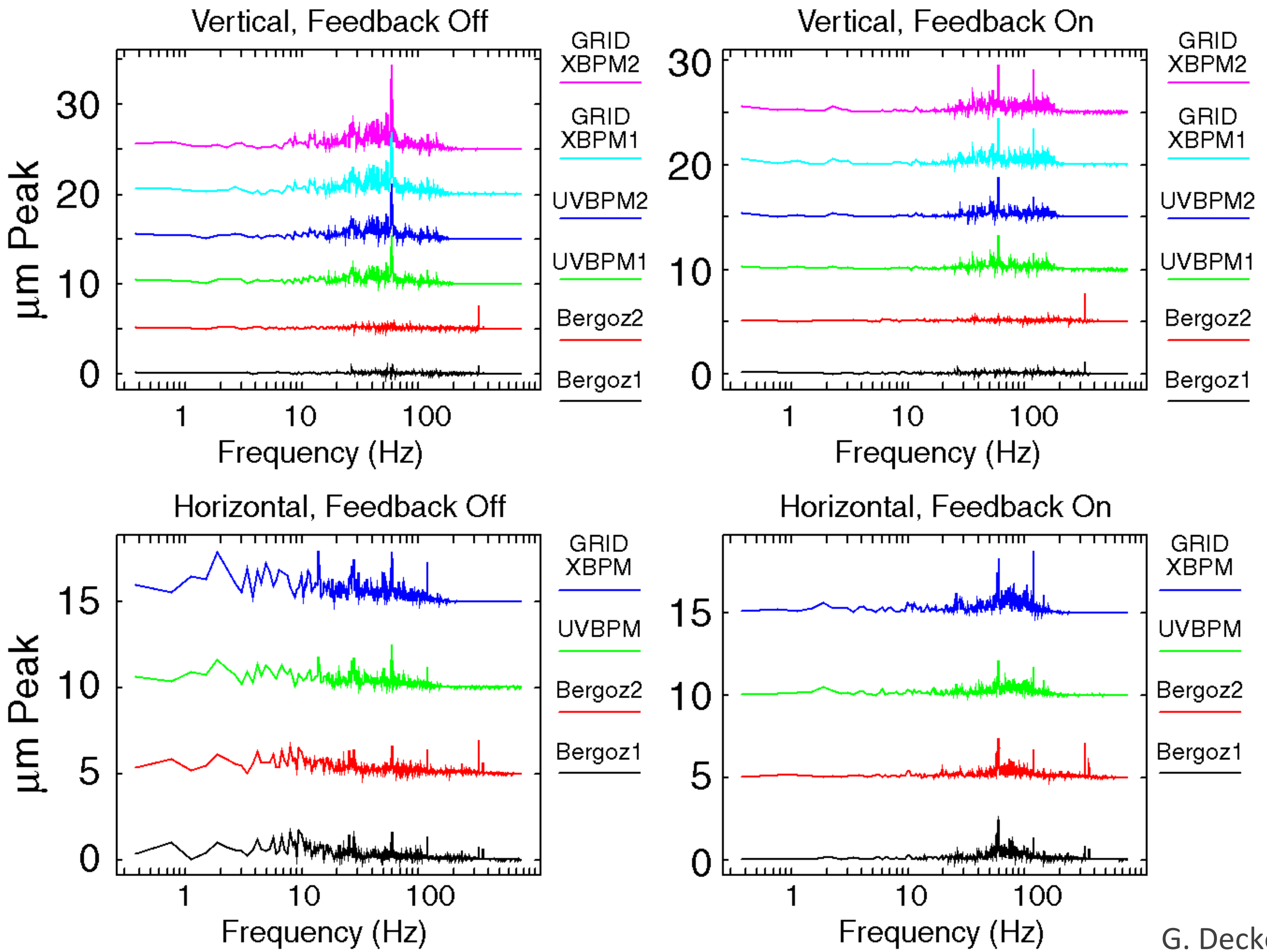
John Carwardine

Noisy BPMs



Note Bergoz w/ 1 cm buttons
Libera w/ 4 mm buttons

Existing Performance Cont'd



G. Decker BIW10

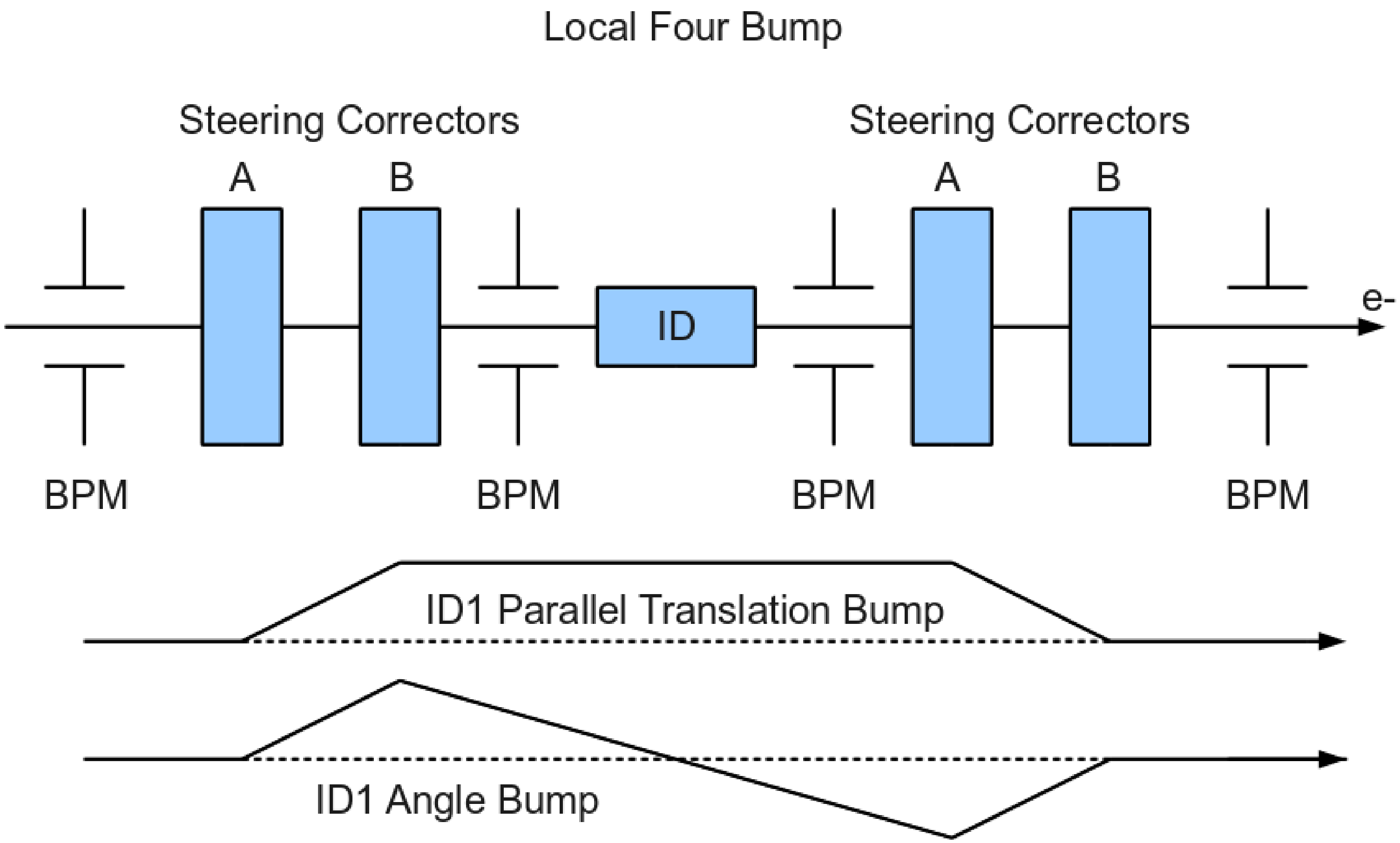
Present and Future Beam Stability

		AC rms motion 0.01-200 Hz		AC rms motion 0.01-1000 Hz		Long-term drift (One Week)	
		μm rms	μrad rms	μm rms	μrad rms	μm rms	μrad rms
Horizontal	Present	5.0	0.85	5.0 - 7.0*	NA	7.0	1.4
	Upgrade	3.0	0.53	6.0	1.14	5.0	1.0
Vertical	Present	1.6	0.80	3.7*	NA	5.0	2.5
	Upgrade	0.42	0.22	0.84	0.44	1.0	0.5

* Measurement up to 767 Hz.

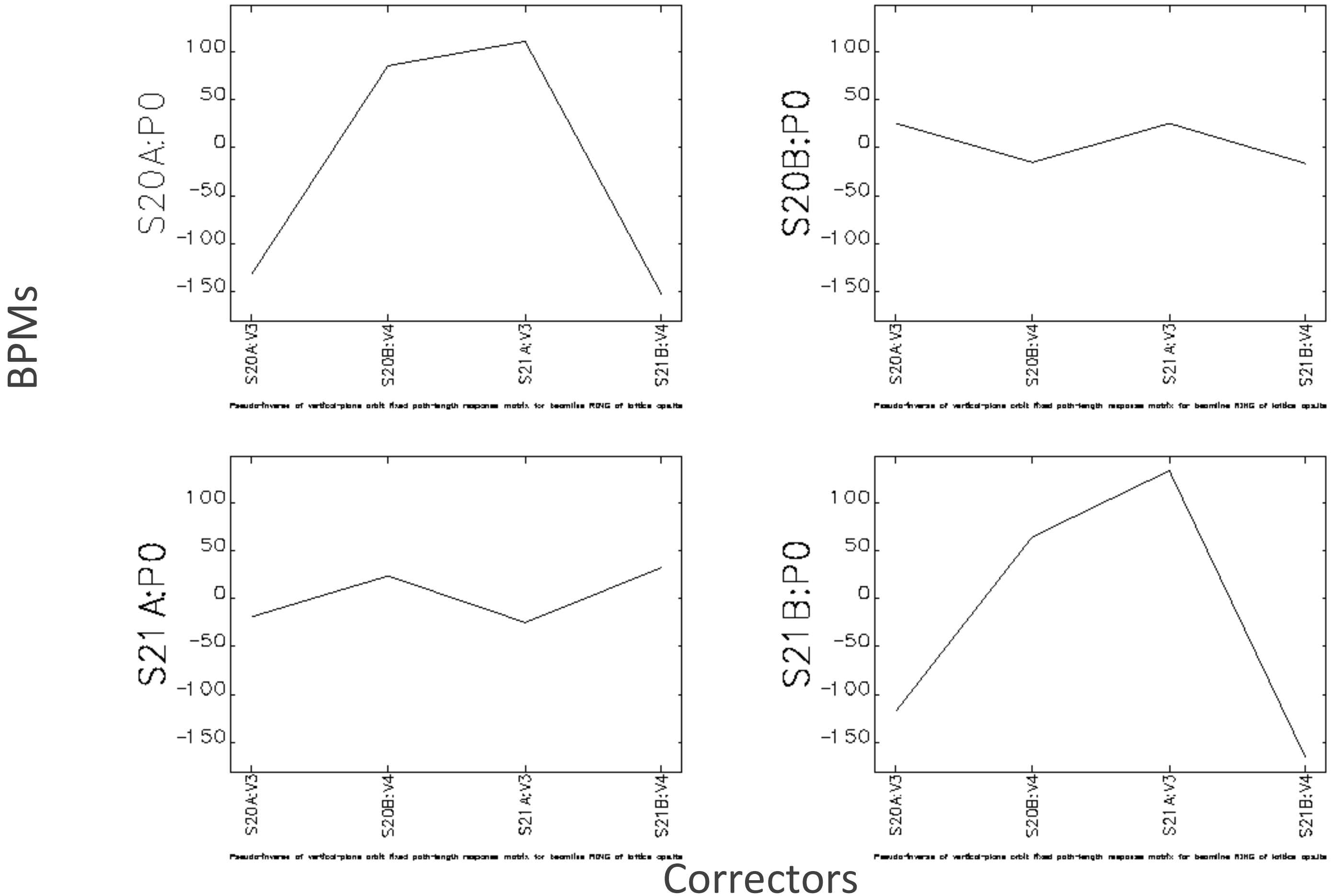
- Based on 5% of transverse beam dimensions up to 200 Hz and 10% up to 1 kHz.

Digression: Spatial Modes 1 – Local Bump



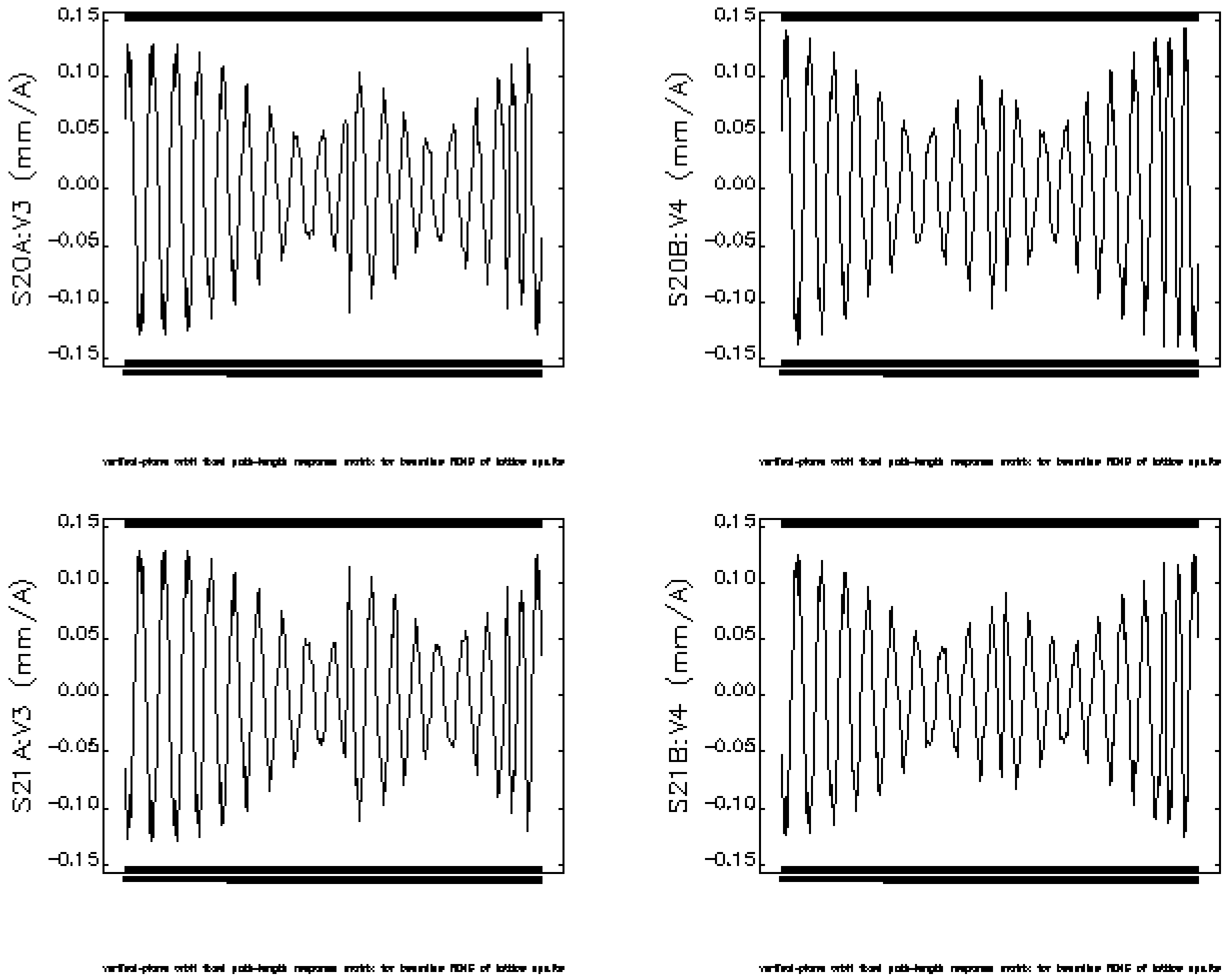
4 by 4 Local Bump Inverse Response Matrix

$$Y_m = R_{mn} C_n \qquad R = U S V^T \qquad C_n = R^{-1}_{nm} Y_m$$



A Better Bump – 4 by 394 Response Matrix

Correctors



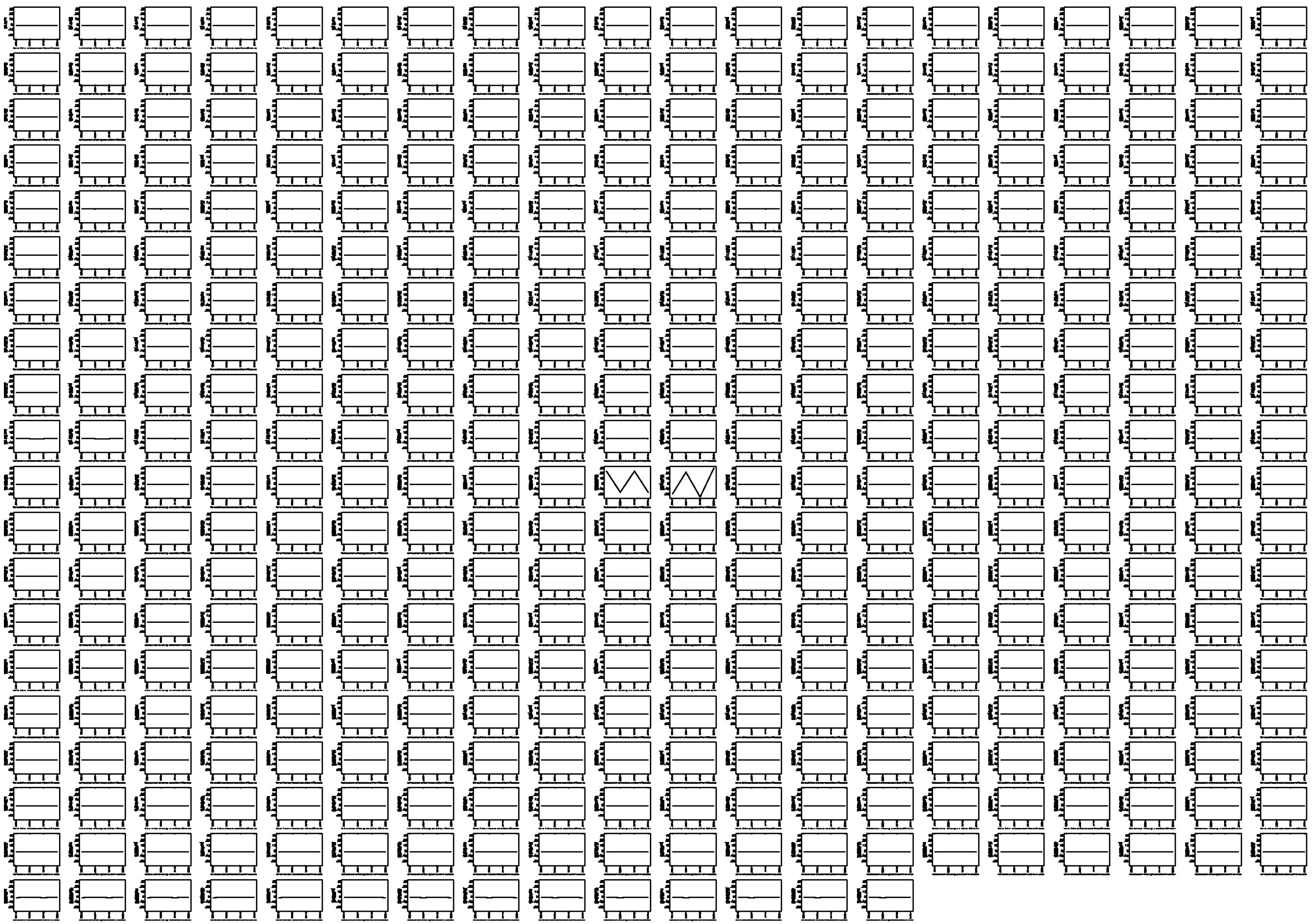
BPMs

Vertical Tune is 19.3

4 by 394 Pseudo-Inverse Response Matrix

$Y_m = R_{mn} C_n$ $R = U S V^T$ $C_n = R^{-1}_{nm} Y_m$

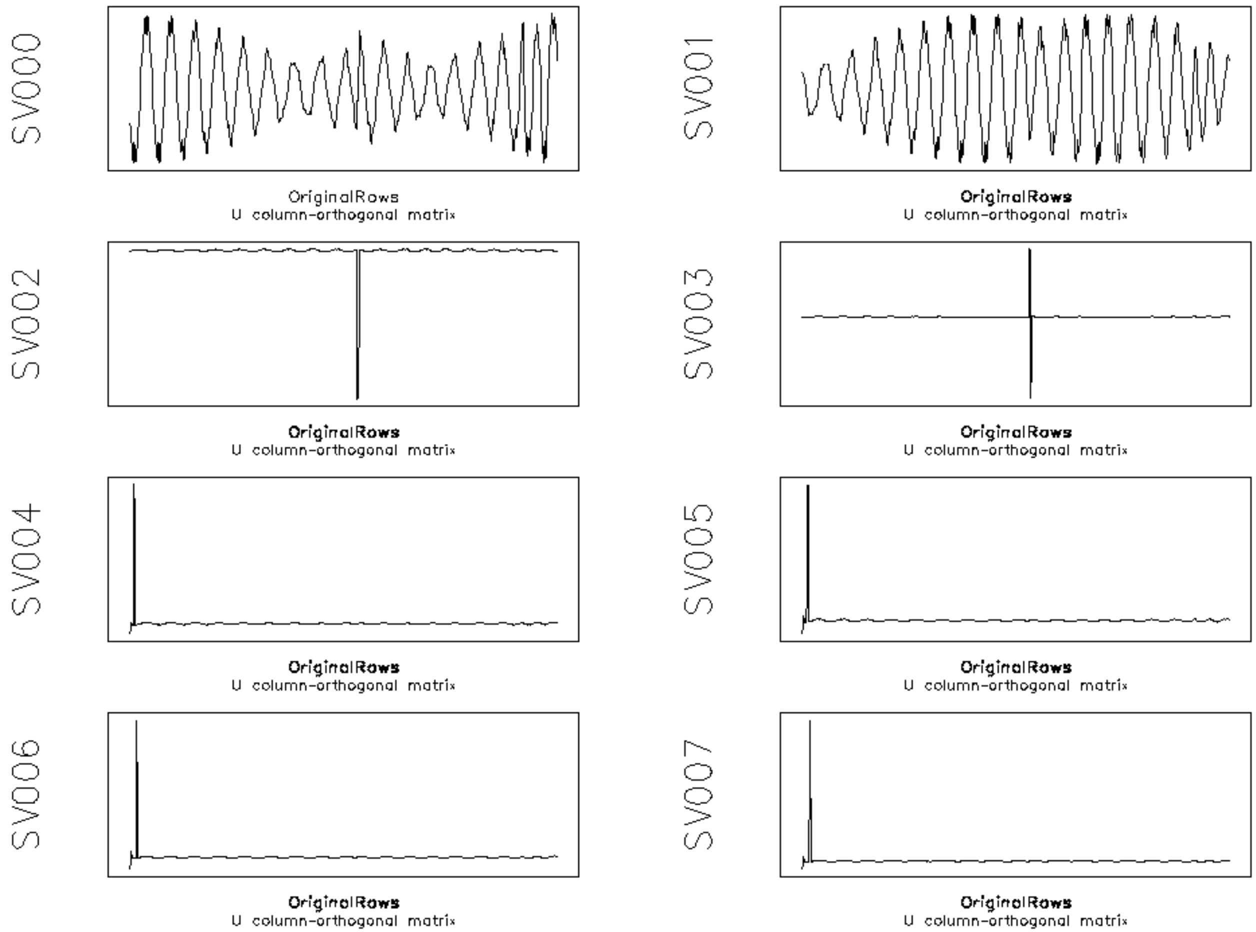
BPMs



Correctors

4 by 394 U Matrix - Eigenorbits

$Y_m = R_{mn} C_n$ $\qquad$ $R = U S V^T$ $\qquad$ $C_n = R^{-1}_{nm} Y_m$



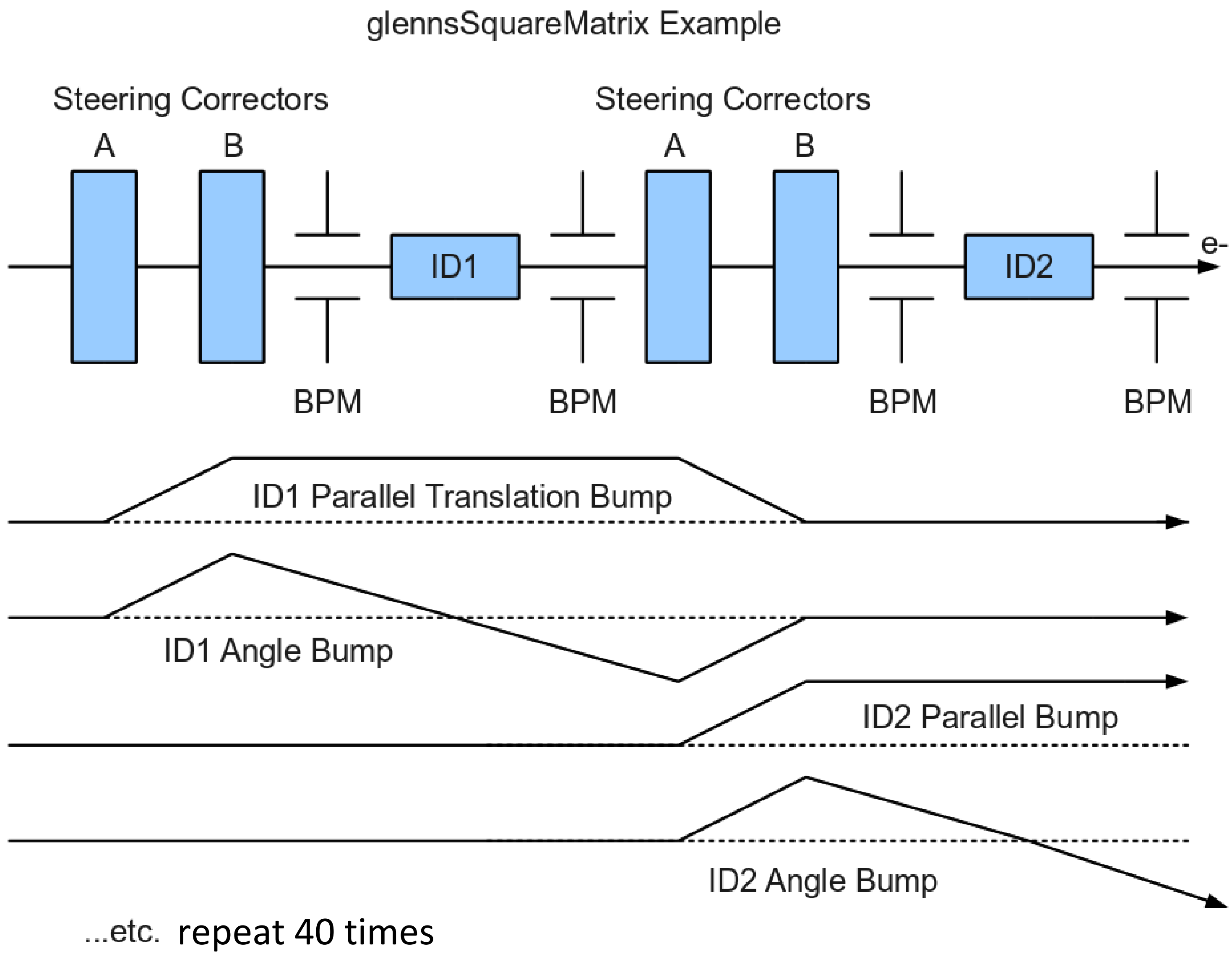
Bump leakage

Parallel translation
And angle bumps

Single-BPM
impulses

A case where lots of BPMS are a good thing

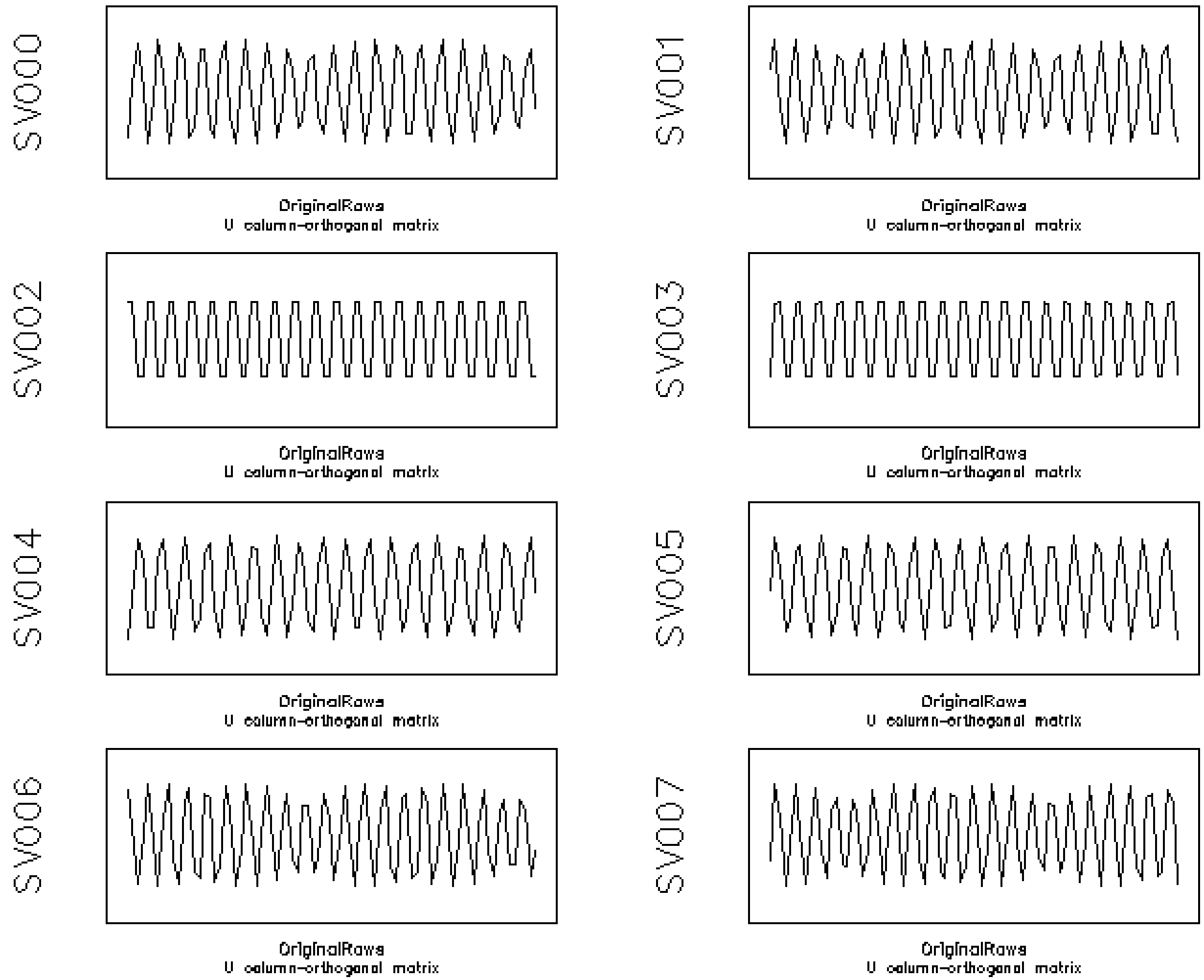
Spatial Modes 2 - An Eighty by Eighty Square Matrix



repeat 40 times

glennsSquareMatrix U Matrix Eigenorbits

Sin-like | Cos-like



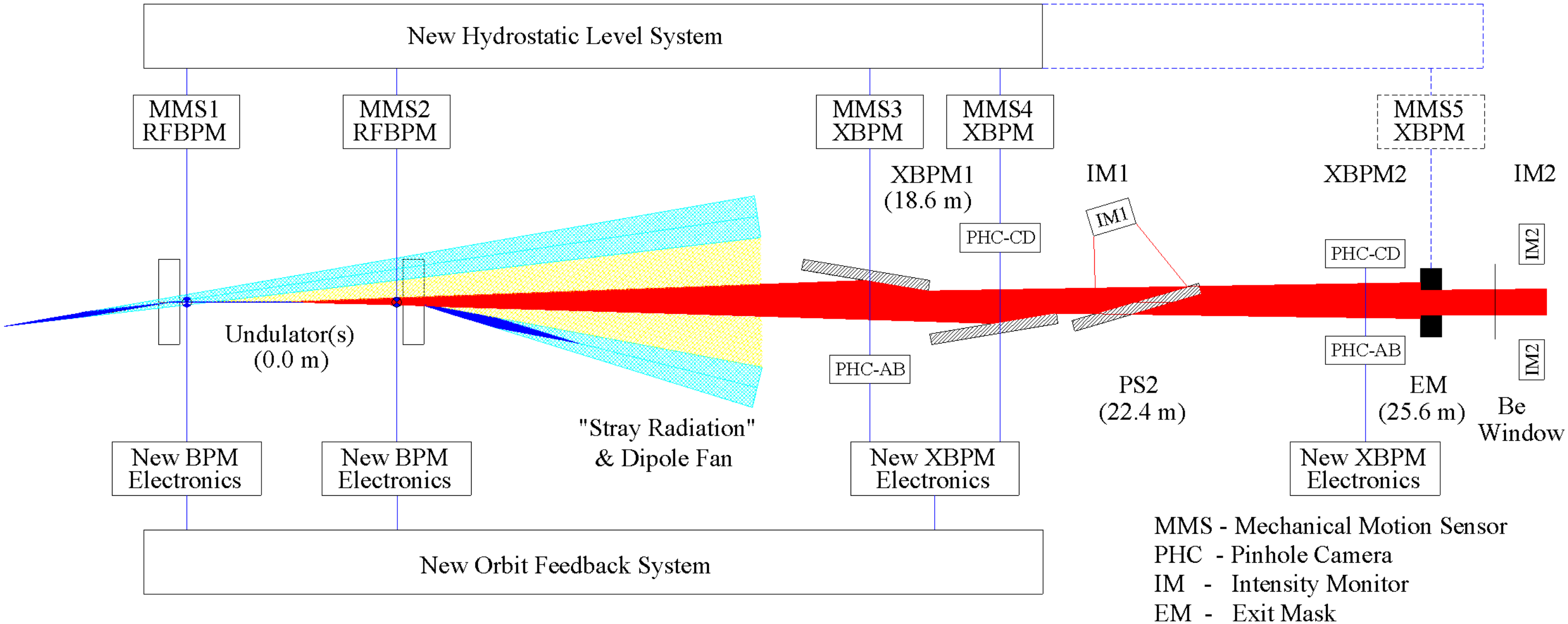
19 periods

20 periods

18 periods

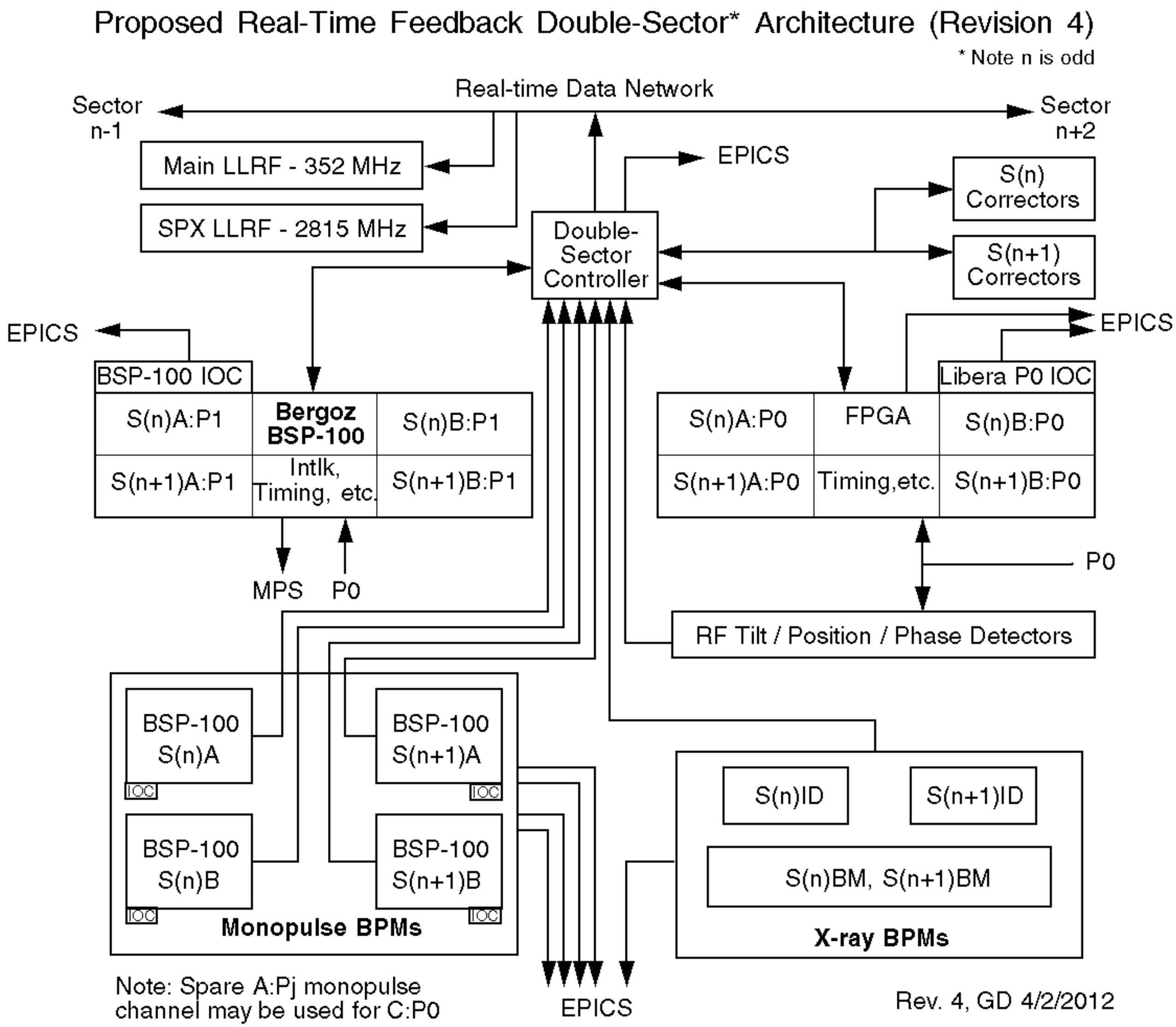
21 periods

Thinking Locally - Sector 27 in September 2014



- Consider doing exact full-band correction on only source RF bpms using something like glennsSquareMatrix.
- Then use second much slower feedback connecting xbpms to rfbpm setpoints.
- Worry about BM beamlines later, perhaps with calibrated slow corrector bumps
- End of digression

What will it look like



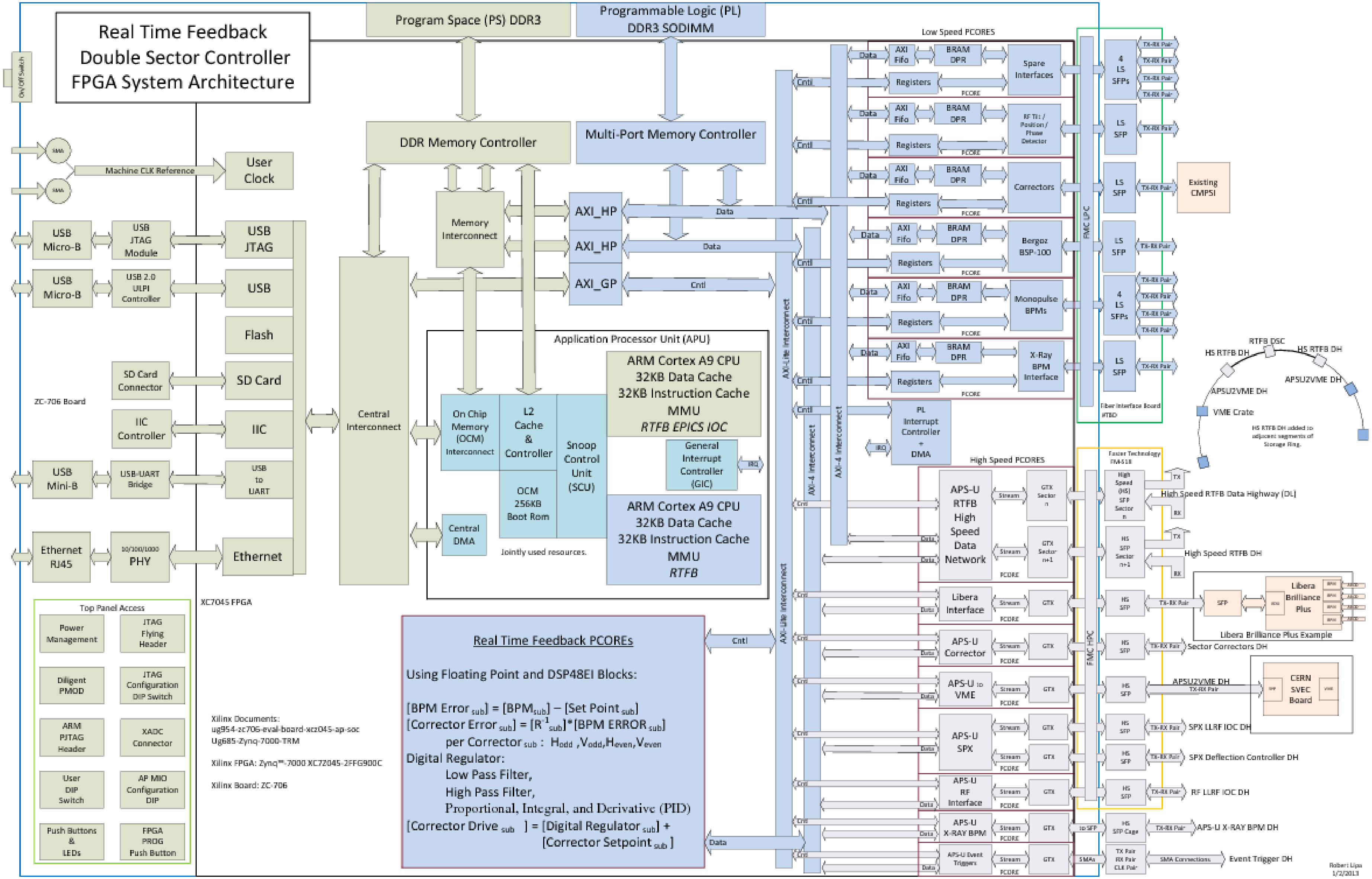
22.6 vs. 1.5 kHz

Access to everything

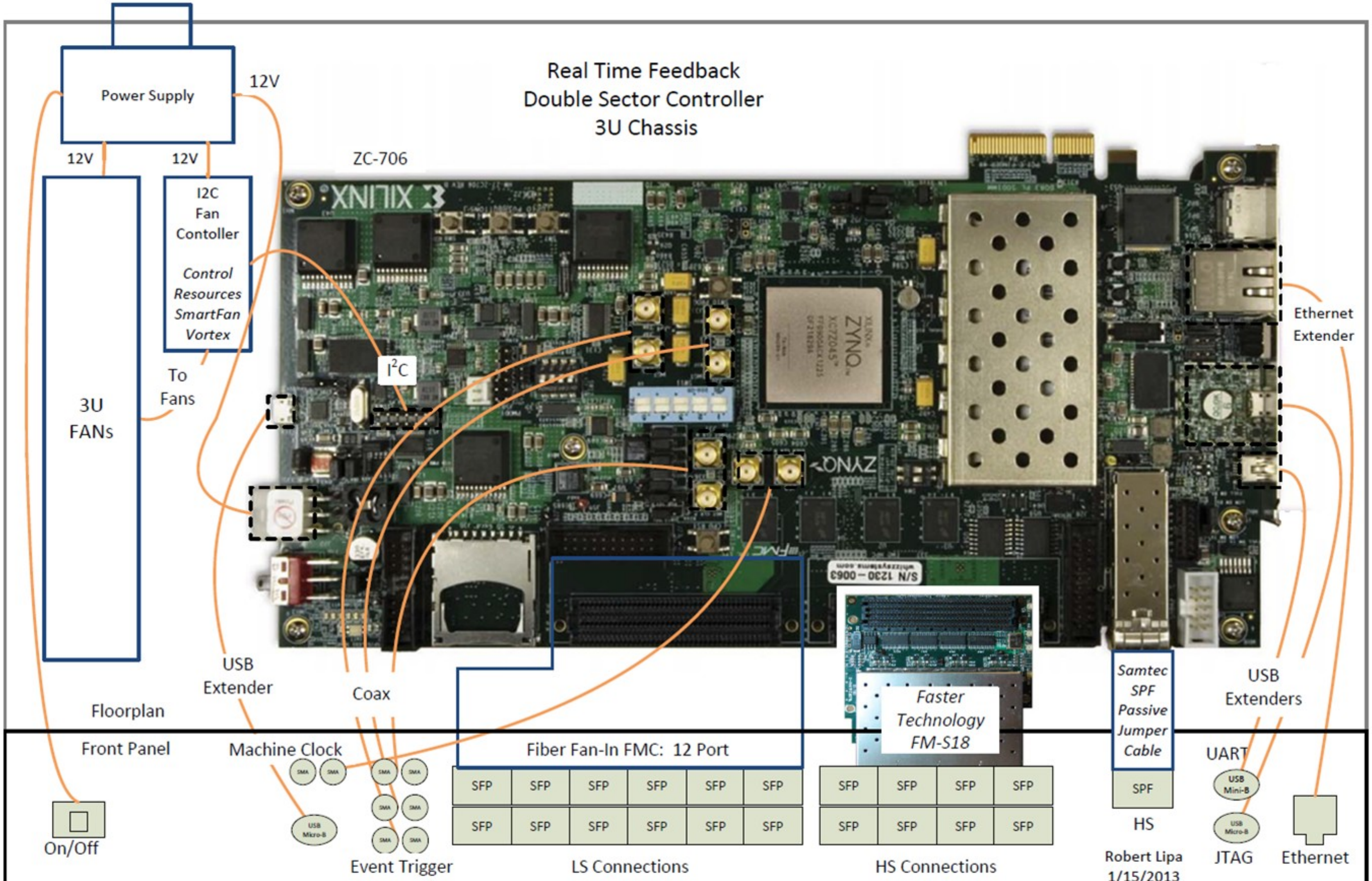
Nominal 200 Hz

Closed-loop BW

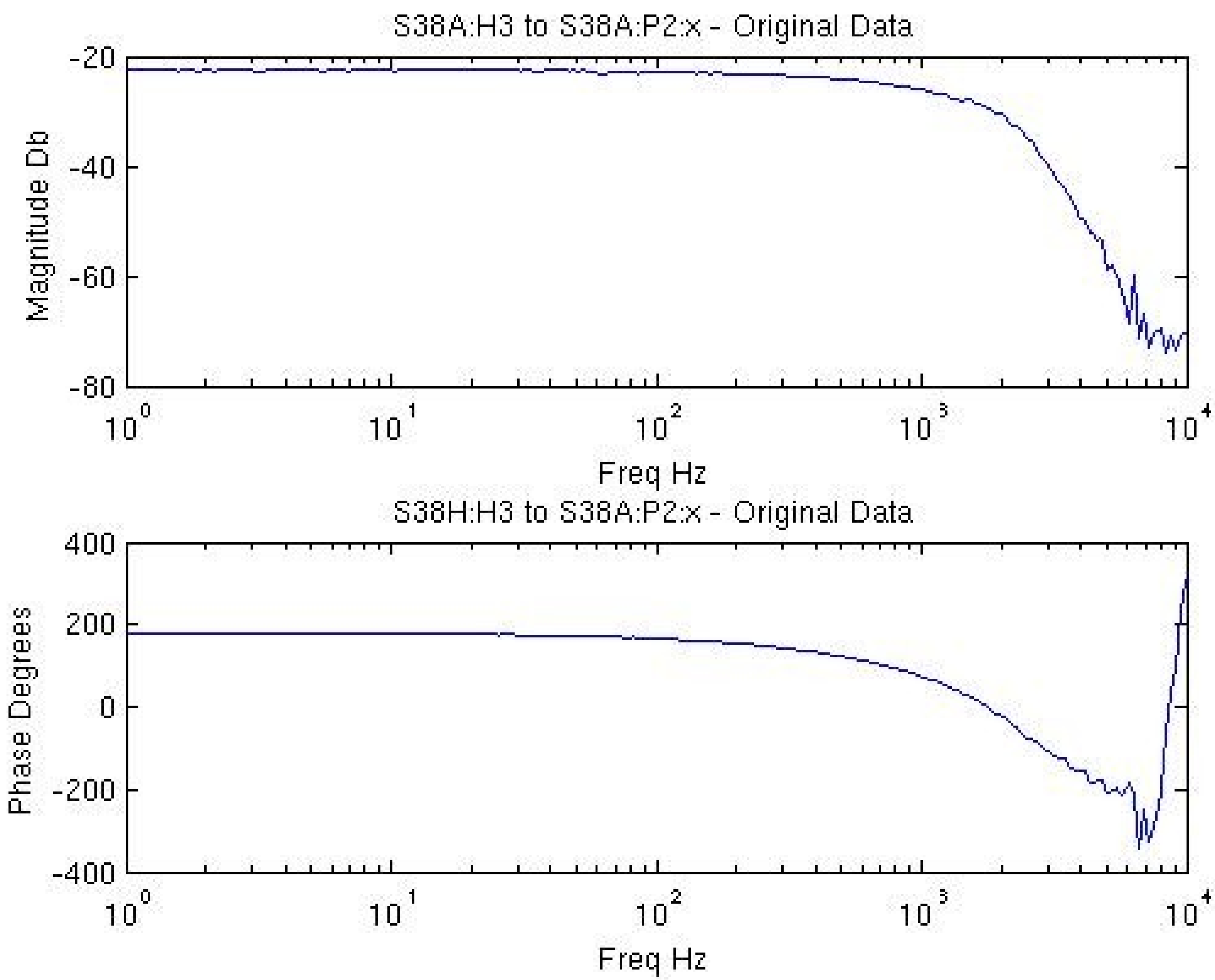
Double Sector Controller Architecture



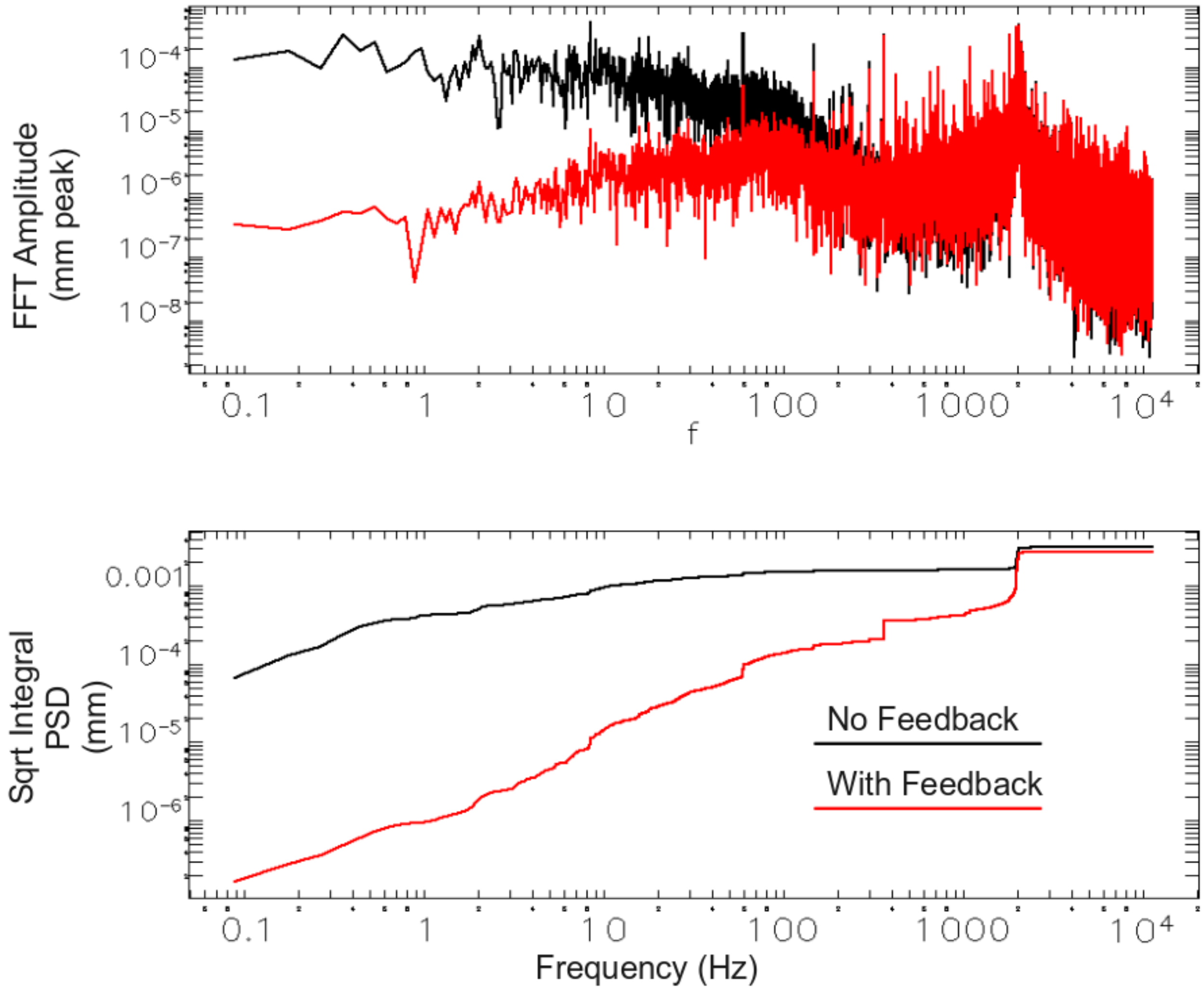
Zynq Board Interfaces



Measured Response S38A:H3 to S38A:P2x Raw



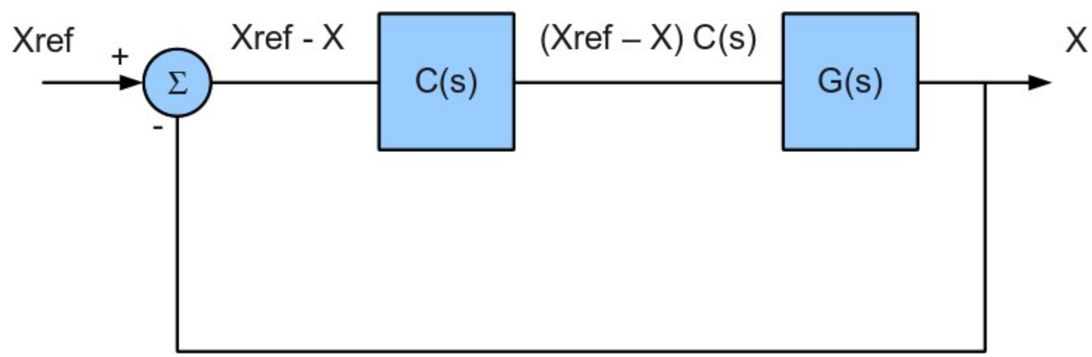
Simulation



FFT Amplitude (mm peak)
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
0.1
1
10
100
1000
10⁴
f
Sqrt Integral PSD (mm)
0.001
10⁻⁴
10⁻⁵
10⁻⁶
No Feedback
With Feedback
Frequency (Hz)

Implementation

C = "The regulator" G = "The accelerator"



$$(Xref - X)\ C(S)\ G(s) = X$$

$$\frac{X}{Xref} = \frac{C\ G}{1 + C\ G}$$

Summary

- APS feedback design is constrained by
  - Existing hardware,
  - 5000 hour operating schedule throughout
  - Installation during three month-long shutdowns / year, 10 total
- Design process is
  - To learn from our own and other's mistakes (this workshop)
  - Comprehensive measurements on the existing accelerator
  - Simulation to refine algorithms in space and time
- First dress rehearsal summer 2014
- Operational deployment September 2014